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Sea Ice Engineering in China

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ABSTRACT

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Chinese engineers found sea ice problems as well as oil in the Bohai Gulf from the late 1960's. This paper introduces the development since then and the present status of scientific research and engineering practice relating to sea ice in this region. The trends in the coming years are predicted.

ADDITIONAL INDEX WORDS: *Offshore engineering, sea ice design criteria, offshore petroleum industry, coastal engineering, ice engineering, sea ice forecasting.*

INTRODUCTION

The first discovery of oil and gas in the Bohai Gulf in the middle of the 1960's encouraged the Chinese petroleum industry and geologists to go offshore. However, the later experience in this area demonstrated the environmental obstacles which are much more serious than were expected initially. Despite the shallow water depth (mostly within 30 meters), the sea ice, earthquakes and mud bottom in the Gulf present a real challenge to offshore engineering activities. Among these "three evils," the sea ice problem seems to be the most difficult one. A drilling jacket and a flare jacket were totally destroyed by the drifting ice in the springs of 1969 and 1977, respectively (Xu *et al.*, 1981; Janbu *et al.*, 1982), and these were unique accidents for offshore platforms in the country due to a weak design, because of the lack of knowledge on sea ice.

The potential oil resources led engineers and scientists to learn more about sea ice by collecting and analysing information from ice sample tests, field measurements and observations, and to improve the structural design of platforms in ice-infested waters.

From the beginning of the 1980's, the Chinese offshore petroleum industry became involved in more international cooperation. Along with this, the sea ice research and related engineering development in China came more in contact with interchanges with the international engineering community. The progress of sea ice engineering in China in the last 10 years is attributed to the sustained effort on particular investigations, and also on the sharing of experiences recently achieved elsewhere in the world.

CONDITIONS AND DESIGN CRITERIA OF SEA ICE IN THE BOHAI GULF

Ice is an annual phenomenon in the Bohai Gulf, where the frost period is usually from the end of November to the beginning of March. The thickness of ice and its extent to the Gulf depend upon the local freezing air temperature in the current winter, and vary from year to year (Xu *et al.*, 1985).

For the sake of reasonable specification of the sea ice design criteria, the Gulf is divided into several zones, according to water depth and the

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meteorological and oceanographical conditions. Figure 1 is a suggestion for the design zone division. To determine a cumulative probability distribution of the maximum ice thickness for each zone, the following principles and procedures have been recently used:

(1) The data for measured ice thickness is limited. There are, however, much longer air temperature records from several meteorological stations along the coast. The measured ice thickness values could thus be extended into a longer series according to the air temperature records and the physical relationship between the maximum ice thickness and the "accumulated freezing degree days" in a year. This relationship is based on thermodynamic principles and usually can be written in a form as:

$$h = \alpha(FDD - 3TDD - K)^{1/2} \qquad (1)$$

where FDD and TDD are the accumulated freezing and thawing degree days, respectively; α and k are coefficients depending upon the local environmental conditions of the specified sea area. Equation (1) was used in Alaska (COTBURN *et al.*, 1984), and it appears to be applicable for the Bohai Gulf. The coefficients *a* and k should be assigned through a regression analysis for different zones. The distinction between sheet and rafted ice thickness data should be regarded in the regression analysis (LIU *et al.*, 1987).

Instead of using equation (1), a more rational thermodynamic model, which is an ice growth time history simulation, can be employed as well. However, a number of meteorological and oceanographical parameters have to be figured in the model, and this may require more experience in the Gulf.

(2) There are "warm" years having no ice in the central zone of the Gulf. This implies that there would be a considerably high value of coefficient k for this zone. A more logical way in this case can be accepted on the basis of the conditional probability concept. Regarding "a year in which there is ice" as a random event, and combining with another independent random event of "the ice is thicker than a specified

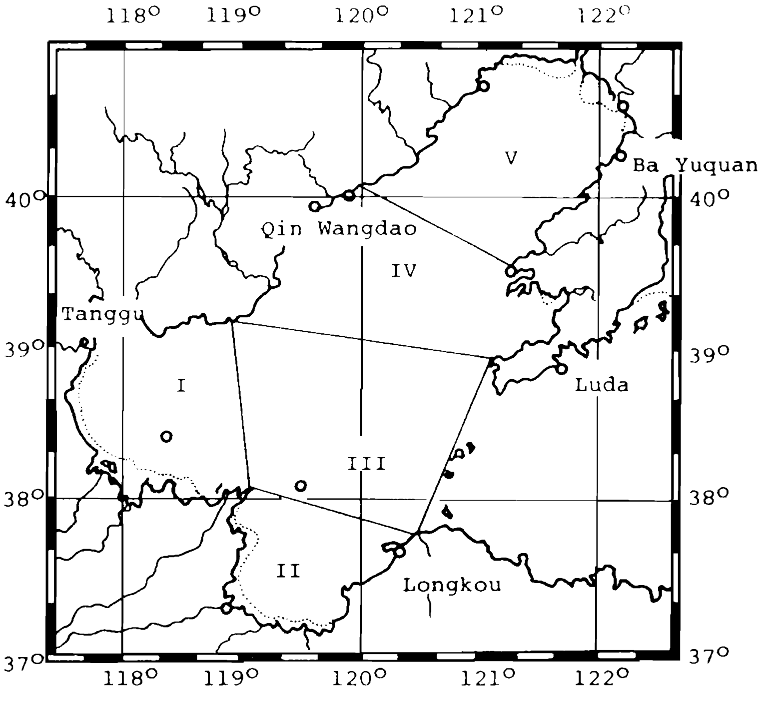


Figure 1. A suggested division of sea ice conditions in the Bohai Gulf.

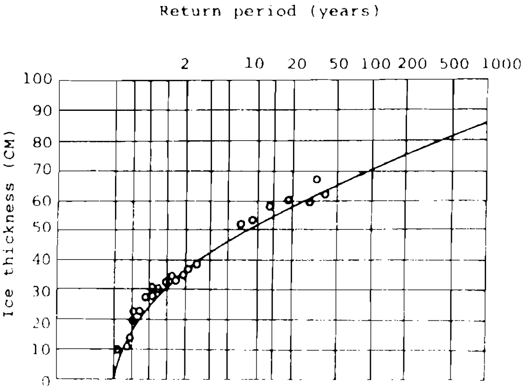


Figure 2. Probability distribution of maximum ice thickness in zone I.

value," one can build up a combined probability model, and determine the probability distribution through the conditional probability calculation (LI *et al.*, 1985).

(3) In fitting the empirical results, several theoretical distributions were tested. Among them, the Gumbel distribution has been used for the design ice thickness estimation (Figure 2).

Sea ice strength is another principal parameter in the design criteria. Since the typical structures so far in the Bohai Gulf are jacket platforms with vertical or basically vertical legs, the compressive strength of sea ice is therefore of much concern.

The Marine Environmental Protection Institute (MEPI) of the National Bureau of Oceanography in Dalian has been doing the sample tests including uniaxial compressive strength tests of the Bohai sea ice since late 1970's (ZHANG *et al.*, 1983; LI *et al.*, 1987). They improved their sampling and laboratory techniques in recent years according to the "Standardized Testing Methods in Ice" recommended by the IAHR Working Group in 1981. In Figure 3 is shown one of their results for the uniaxial compressive strength (horizontal loading direction) vs. loading rate curve of the Bohai sea ice.

The peak compressive strength of sea ice can be roughly estimated by an empirical formula as, for instance, given by VAUDREY (1977) when salinity and temperature of the ice are known. The results both from sample tests and empirical estimation indicate the peak uniaxial compressive strength values (loading horizontally) of the Bohai sea ice in the range of 1960–2354 kPa (200–240t/m^2). This is substantially lower than the corresponding values for Arctic ice.

Rafted ice is a common occurrence in the Gulf, and is generally doubly-layered according to field observations. Considering the practical situation, the design compressive strength for the rafted ice is usually taken to be 80–90% of the sheet ice strength.

Engineers have also taken notice of the possibility of application of the Monte Carlo method in the sea ice design criteria, and the method is also aimed at the reliability estimation for the designed structure. This will be used when a mature information situation has been achieved.

INVESTIGATIONS ON SEA ICE FORCES AND ICE-INDUCED VIBRATION

The following critical situations of ice loads should be considered in the design of a platform in the Gulf: (1) The ice force on the structure may reach its peak value in a sustained low strain rate ($\epsilon < 10^{-4}$ 1/s), accompanied by a creep deformation of the ice. This static situation may happen in the Gulf when the tidal current comes to an equilibrium, *i.e.* the ice velocity approaches zero (this occurs four times a day, and persists for minutes each time); and also when the structure is frozen in ice in a rather cold year. (2) In higher ice velocities, the ice will be continuously fractured or crushed, and the dynamic interaction between ice and structure will happen in the case of a flexible structure. This dynamic situation implies a sustained, perhaps violent, vibration of the structure, which may lead to a failure due to structural fatigue.

A static analysis of the structure under the ice load in the creep mode of the ice must be considered for the first situation. Meanwhile, it is necessary to look into the ice-induced vibration process in the second condition. In the latter case, the ice will behave in its fracture mode.

Chen Xing *et al.* of the Tianjin University first made an investigation of the ice load on a cylindrical structure by a nonlinear viscoplastic analysis (CHEN, 1986). In the analysis the ice is considered to be an isotropic and visco–perfectly plastic material. An existing mathematical creep model of ice under an uniaxial

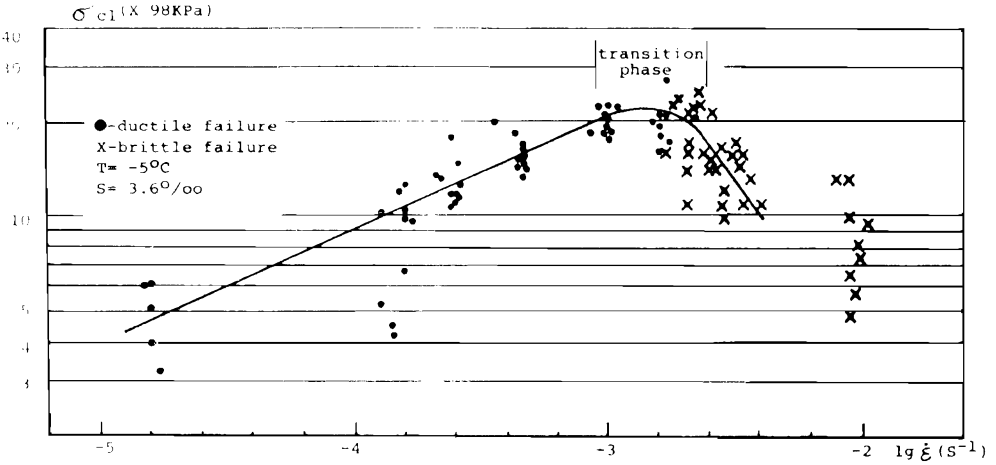


Figure 3. The uniaxial strength (σ_c) vs strain rate (ϵ) curve of the Bohai sea ice.

stress condition is extended to a triaxial model by using the theory of viscoplasticity. The finite element method is used in the creep analysis, and the results are compared with those of some other methods (plastic limit analysis, reference stress method and so on). It is indicated from the results that the effect of viscous properties of ice should not be ignored when a sufficiently slowly-moving ice sheet moves against a structure.

The sea ice research group at the Dalian Institute of Technology has done a series of laboratory and theoretical investigations on mechanical properties of the Bohai sea ice, such as the strain rate sensitivity of strength, the creep behavior and the fracture toughness, which are all aimed at the sea ice force machanism (Shen *et al.*, 1986; Shen *et al.*, 1987; Ji *et al.*, 1988).

Ice-induced vibration was displayed prior to structural failure both on the collapsed drilling jacket in 1969, and on a dormitory jacket which survived after the vibration in 1977. The research group for sea ice engineering at Tainjin University has been doing a sustained investigation on this problem since 1977, starting with the field observation of the vibrating dormitory platform being crushed by ice. They looked into the mechanism first by making a test analysis of the available mathematical models (Xu *et al.*, 1983). On the basis of the self-excited vibration theory, which seems convincing from the comparison of the results of analysis and observation in the field, an improved model—the "ice-force oscillator model" was suggested for analysis of the dynamic ice-structure interaction (Xu *et al.*, 1988). The model considers the potential frequency and the self-excited behaviors of the dynamic ice forces, and can be used for both flexible and rigid structures. However, a number of empirical parameters in the model have to be assigned according to the results of a systematic model test.

MODEL TEST AND FIELD MEASUREMENT OF ICE FORCES

The physical modelling of ice-structure interaction provides an opportunity to demonstrate the behaviour of a structure designed for resisting ice loads before the type and dimension of the structure are finally determined. The phenomena which would happen in the field can be reproduced in the model test, and the main parameters indicating the phenomena can be controlled and changed separately. The theories in ice mechanics and the results of ice load calculation can thus be particularly reviewed in the model tests. The model test technique has so far been accepted by most engineers as an efficient and economical measure in solving ice problems. A number of ice model tanks (basins) with various dimensions were erected in the past ten years in the world. The biggest among them is 80 m × 12 m × 3 m, and the smallest is 6 m × 0.9 m × 0.6 m.

The first ice model tank in China was built and started operating in 1987 at the Tianjin University (SONG *et al.*, 1988). The dimension of the small ice model tank is 5.5 m (length) by 1.91 m (width) by 0.8 m (depth) as shown in Figure 4. It is located in a 6.3 m × 3.6 m × 2.98 m cold room which is temperature-controlled by a refrigerator, and the lowest temperature in the cold room is − 22°C.

A constant speed carriage moves along the tracks which are installed on the top of the walls of the tank. The carriage is used to create the ice-structure interaction under different loading rates, simulating the ice movement in the field driven by wind or current and its interaction with the structure. The carriage is driven by a stepless speed regulation, and moving at any specified constant speed between 0.1 ~ 67.6 mm / s. This in fact covers a fairly broad range of strain rate in ice. Two alternatives can be chosen in the test: pushing ice (with the model structure fixed on the bottom of the tank) or pushing the structure (with the model structure fixed on the carriage).

The perforated ceiling over the tank is used for the uniform distribution of the air temperature, and the compensation of the air pressure in the ice growing process.

The ice forces applied on the model structure are detected by strain gauges and accelerometers on the model structure, and the signal is transmitted into the YBD-1A strainometer, and then to an IBM-PC computer through an analog-to-digital converter for data acquisition, processing and analysis.

The ice-structure interaction model test is even more complicated and more difficult to carry out than a conventional fluid or structural model test, due to the similarity requirement for the model ice, including the similitude in its deformation and strength characteristics as well as in its integral movement behaviors. Generally, the Froude numbers and Cauchy numbers must be respectively the same in full-scale and model situations (TIMCO, 1984). It is of importance to keep not only the strength of the model ice in accordance with the specified model scale, but also the elastic modulus to flexural strength ratio E / σ_f in the model ice as close as possible to that of the real ice. Much

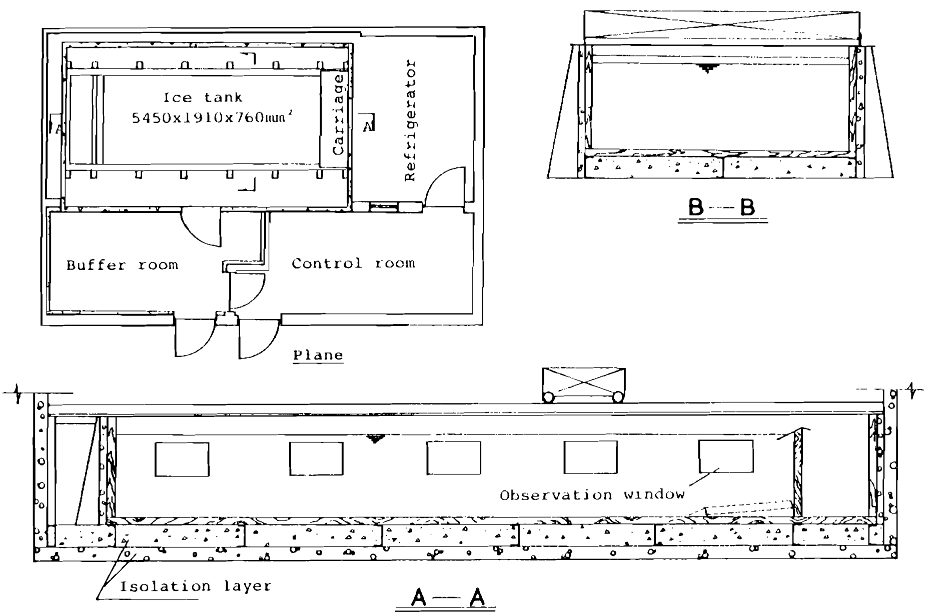


Figure 4. The ice tank No. 2 at Tianjin University.

effort has been made in this connection by scientists of the world. It is reported that when the saline doped ice is used and the model scale is larger than 20, the ratio E / σ_f of the model ice will become too low to simulate real ice. TIMCO (1979) suggested a new recipe of carbamide for the model ice, and satisfactory results were displayed in the tests. Now, the carbamide has been in use at other ice model basins. In addition, there are some inventions of new materials for model ice which are confidential.

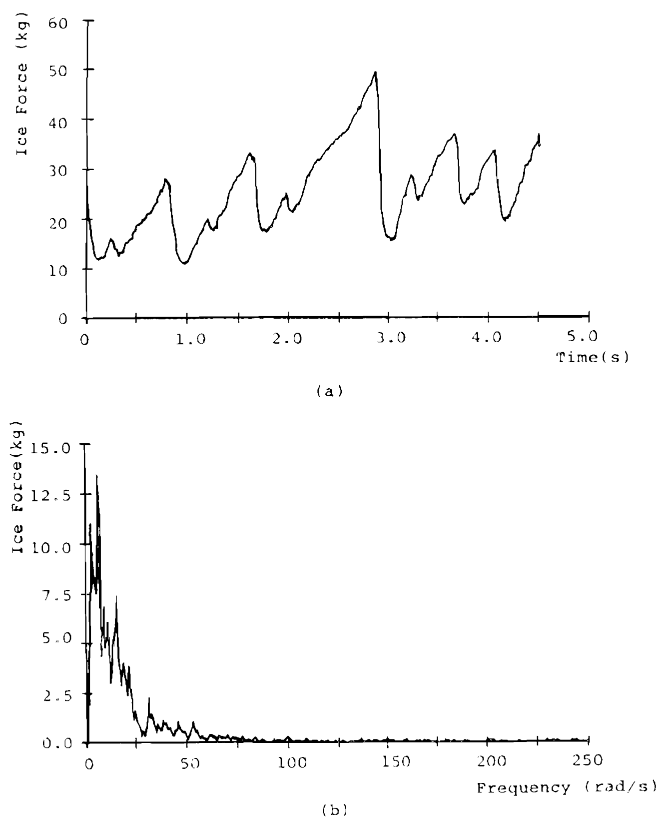
In our primary experience, we used in sequence the saline-doped and carbamide-doped model ice. The model ice displays a dominant columnar structure but a thin surface layer of randomly-oriented crystal ice with a higher strength than that of the lower layers. The strain modulus E and flexural strength σ_f of the model ice are measured in situ before towing the carriage to make ice-structure interaction. The typical values of the modulus E and flexural strength σ_f of the carbamide-doped ice are 81800 kPa and 26.7 kPa (implying a scaling factor of about 20), respectively, and this gives a ratio of E / σ_f of about 3000.

In the first tests carried out in the newly established tank, a single cylindrical structure was used to simulate the monopod structure in a concept design of the ice resistant platform in the Liao-dong Bay. For the first stage, we used a "rigid" cylinder to look into the "static" ice loads in the test, ignoring the influence of the structural motion.

As an indentation and penetration test, the failure patterns of the ice sheet in various carriage velocity v (or strain rate ϵ = v / 2D) and aspect ratio (D / h) are first observed. It was shown in general that while the crushing model always appears in high velocity and low aspect ratio situations, the buckling dominates when a wide structure is impinged upon by a slow and thin ice sheet. This is in accord with the results available in the literature. In Figure 5, (a), a typical ice force time history is given, taken from the records of the test (D = 15cm, h = 3cm, v = 4cm / s). The time domain data can be transformed into the frequency domain by an FFT analysis, and Figure 5, (b) is the corresponding ice force spectrum thus obtained. From the spectral curve it is noted that a dominant frequency appears which is usually called the "characteristic frequency" of a crushing ice sheet in the literature. Our test results show a tendency for increase of the characteristic frequency with an increase of the carriage velocity, and this gives support to the work by SODHI *et al.* (1986). The characteristic frequency can be regarded as a feature of the ice sheet itself independent of the structural condition, and this would make a contribution to the theoretical explanation of the ice-induced vibration of compliant structures.

Now a systematic investigation of model ice technique, as well as a study of ice-structure interaction is in progress, by using the small ice model tank. Meanwhile, a bigger tank is also under construction at Tianjin University (Figure 6).

The ice force measurement on a real Bohai jacket was first planned from the early 1970's, and several instrument systems were even installed on the rebuilt jacket after the accident in the central portion of the Gulf. Unfortunately, the measurement failed finally due to the rather light ice conditions around the jacket in the subsequent winters. The field measurement project was continued in the 1980's. The new instrumented jacket is a four legged well-head jacket located in the center of the Liao-dong Bay where the ice condition is usually much heavier than that in the center of the Gulf. The field measurements were performed in the winters of 1988–1989 and 1989–1990, and the following ice force sensor systems were attached on the jacket on the fabricating yard before installation of the jacket in the summer of 1988: (1) Load cells, which are distributed on the surface of 2 columns within the tidal range for directly measuring of ice pressures on the column. (2) Accelerometers, fixed on several points close to the joints of the jacket for measurement of the structural responses. (3) Strain gauges, stuck on the columns and braces near the sea bottom for sensing the deformation of the jacket under the total ice loads. The results from the above measuring systems can thus be compared with each other. The data process and analysis were carried out at the land base and a set of computer software for this purpose was used. This 2-year project of field measurement of ice forces was finally accomplished cooperatively by BEDC of China and HSVA of West Germany in 1990.



(a)

(b)

Figure 5. Ice force variation on a rigid model structure and its spectrum

THE CONCEPT DESIGN OF ICE-RESISTANT PLATFORM

The majority of the existing offshore platforms in the world are jacket platforms, and so far this was true in the Bohai offshore oil development as well (Figure 7). While the jacket platform has its adaptability to the soft mud bottom condition in the Bohai Gulf, the shortcoming in its ice resistant capability has raised a question in its further employment. In the Lioa-dong Bay, the northernmost portion of the Bohai Gulf, the ice loads are always predominant in the structural design of the platforms. For the platform with slender members like a jacket, the ice forces may be as high as 3 ~ 7 times the wave forces. The only way to enhance the ice resistant capability of a jacket would be by increasing the diameter and the driven depth of the piles, and this may give rise to some difficulties in installation (for instance, a much bigger hammer for driving piles may be required), as well as increasing the total cost. It would not be realistic to remove a jacket platform after a production period to a new site, to return to operation. This reduces the adaptability and flexibility of the jackets in the early production of the oil field and the marginal field development. In addition, the dynamic effect of the ice forces on the jacket platforms would be much more severe than that of the wave forces under the shallow water conditions in the Bohai Gulf. Therefore, it has been a general topic and interest for both the petroleum industry operators and the offshore structural engineers to seek a new type of platform appropriate to the Bohai conditions instead of the traditional jacket.

There was a joint research project performed by the Bohai Engineering and Design Company

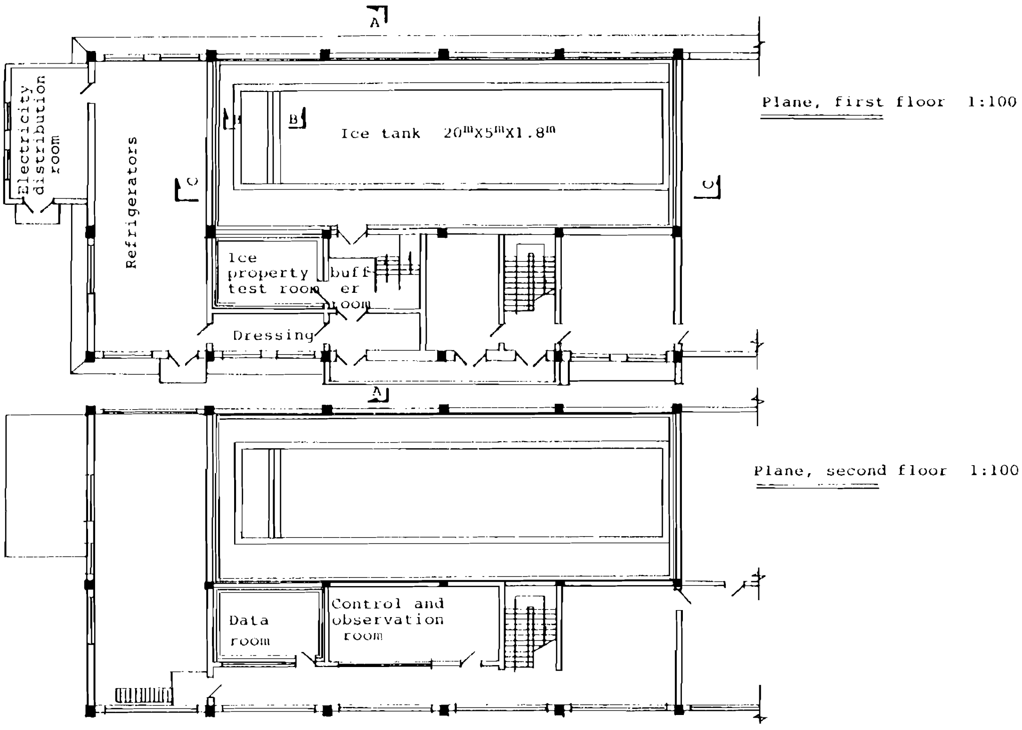


Figure 6a. The ice tank No. 1 of Tianjin University

(BEDC) and some universities in 1986 on the feasibility study of the deeply embedded ice resistant platform for the Liao-dong Bay offshore oil production (Xu *et al.*, 1987). As an illustration of this type of structure, a wellhead production platform with a single column is shown in Figure 8. Comparing the jacket platforms, they mainly have the following peculiarities: (1) Fewer in number and greater diameter of the columns. (2) Elimination of piles. The foundation consisting of several separated caissons can be sunk to a soil layer under the ground surface having required bearing capacity with the aid of the "mud suction and drainage system"(MSD system) in the caissons. (3) Re-use of the platform. By operating the MSD system as well as letting out the water in the volumetric foundation structure, the platform can be pulled out of the soil, and raised into a floating state. It can then be towed to another site for a new production cycle. (4) A vibration isolation system is fitted out between the deck structure and each column.

In the proposed platform configuration, the contact area of the structure with ice is reduced as compared with that of the jacket platform, and the conductor pipes are all penetrated through the large diameter columns. The ice jamming problem is therefore much reduced, and the condition of the ice-structure interraction is considerably improved. The experience of the jacket platforms in the years with heavy ice in the Bohai Gulf indicates their sensitivity to the dynamic ice effect. There is evidence from the field measurement, and laboratory tests supporting the self-excited vibration theory as an explanation of the ice-induced vibration. A jacket platform and two deeply embedded platforms with a single column (the wellhead platform) and four columns (the oil processing platform), respectively, are analyzed separately in their dynamic stability and response history according to the self-excited vibration theory. The same sea ice and oceanographic conditions and the same production requirements are assigned in the analysis of each platform. The

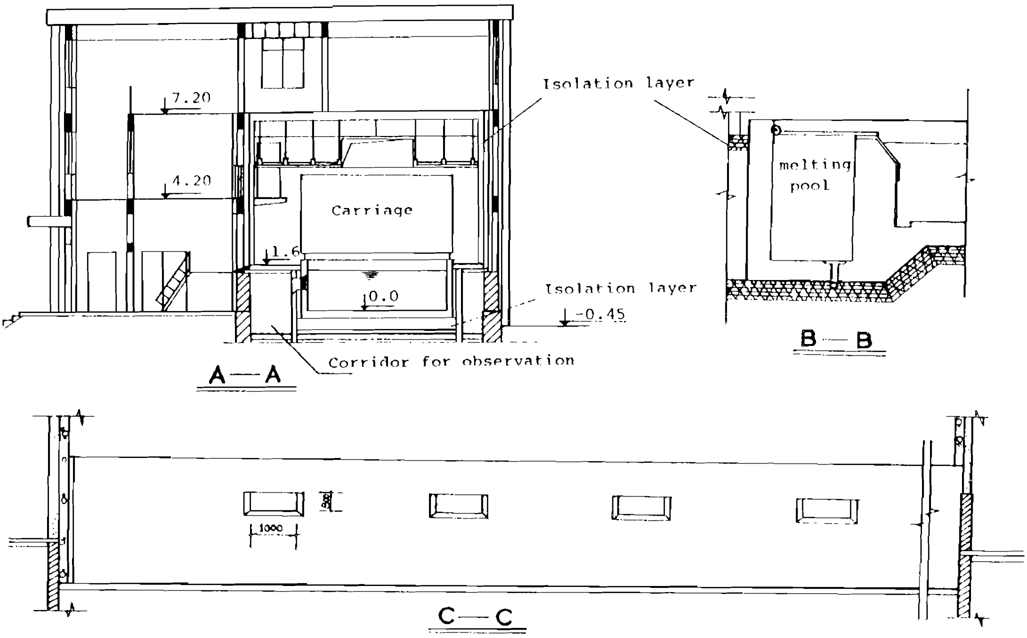


Figure 6b. The ice tank No. 1 of Tianjin University

following inequality is used to determine if the platform will be unstable dynamically, *i.e.* the self-excited vibration will not occur when the inequality is true (MAATTANEN, 1978):

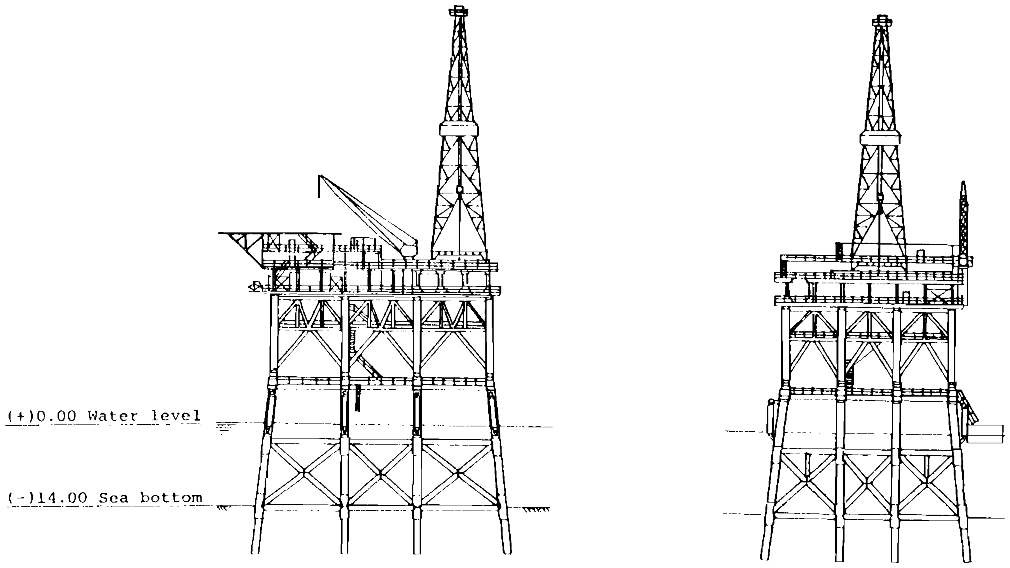
$$\xi_i > \frac{\phi_{nn}\sum_{1}^{m}\psi_{ni}^2}{2\omega_i M_{ii}} \qquad (2)$$

where: ξ_i = damping ratio of the *i*th mode
ω_i = circular frequency of the *i*th mode
M_{ii} = modal mass of the *i*th mode
ϕ_{nn} = negative damping coefficient, implying the dynamic ice force in the n degree of freedom when the structural velocity is unity
ψ_{ni} = modal value of the *i*th mode in the n degree of freedom applied by ice
m = number of columns which are exerted by ice, unique diameter is assumed

In case of instability, the stationary solution or the limit cycle of the self-excited vibration would be requested, and this can be obtained by a numerical integration according to a given $\sigma_c \sim \sigma$ curve. From the results it can be deduced that the single-columned, deeply-embedded platform behaves most stable against ice-induced vibration, and it sustains its dynamic stability (*i.e.* automatically coming back to the origin after an exterior excitation) when the ice thickness is 1.2 m. In contrast, the jacket platform is most sensitive to ice-induced vibration, and its vibrational amplitude at the deck level is 24 cm when the ice thickness is 1.2 m. The behavior of the four-columned oil processing platform in ice-induced vibration is something in between those in the above two situations.

SEA ICE FORECASTING AND MONITORING

The long term and short term forecast and monitor program of sea ice for operation and design of the platforms become of great importance due to the large variance in sea ice conditions in different years, and the unknown movement characteristics of various ice types



West elevation South elevation

Figure 7. A jacket platform in the Chengbei field, Bohai Gulf

(level ice, rafted ice and ice ridges) in the Gulf. The following measures were taken in the last few years for this purpose, and they were mainly carried out by the Research Center of Marine Environmental Forecasting, the Institute of Marine Environmental Protection, the Institute of Ocean Technology (all three belong to the National Bureau of Oceanography) as well as the Bohai Oil Company (1) Sea ice reconnaissance by radar. The first radar antenna along the coast of the eastern Liaodong Bay near the port of Ying-kou went into operation in 1981. The extent of reconnaissance is 12 nautical miles. The data of movement (direction, velocity) and deformation of the ice floes within this range can be obtained from the photos of the radar images and the time sequences of the radar charts. Another antenna with larger range of reconnaissance was installed in 1984. (2) Icebreaker cruises with the aim of field observation and measurement have been performed twice a winter since the late 1970's. However, the data is not continuous, and the icebreaker can not go into ice thicker than 0.8 m due to its power limitation. (3) Aerial survey and remote sensing of the principal sea ice parameters (ice thickness, ice temperature, type and dimension of ice, *etc.*). The first test was carried out in 1985, and it is possible to have a whole picture of instantaneous sea ice conditions in the Gulf by this technique in case of necessity. (4) Satellite-derived data on sea ice. The international satellites have been used in oceanographic measurement for more than 20 years in the country, and the employment of satellite-derived data for the purpose of sea ice measurement was just started a few years ago. The data can be used for indicating the type, extent, concentration and time variation of sea ice in the Gulf. (5) Numerical predictions. The research projects and experimental calculations were performed, and several numerical models for instance, the model described in WANG *et al.* (1985) were carried out considering the thermodynamic and dynamic processes as well as the melting process of the sea ice according to the environmental peculiarities in the Bohai Gulf. (6) Sea ice forecasting by statistical and semi-statistical methods. The statistical correlations between the oceanographical and meteorological factors and the sea ice grades in the Gulf are determined and

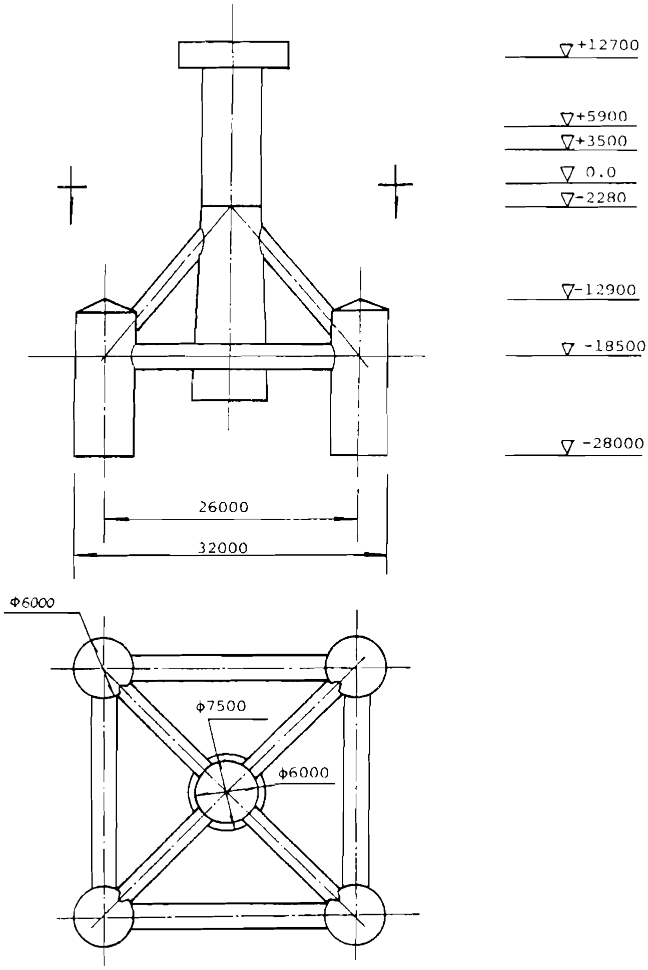


Figure 8. The substructure of a proposed single columned ice-resistant platform

are used as a basis for sea ice forecasting. In addition, some physical relationships are drawn into the analysis in forecasting of the sea ice parameters (for instance, the ice thickness).

CONCLUDING REMARKS

The development of sea ice engineering in China made its first step in the last ten years on the background of the promising discovery of oil and gas in the Bohai Gulf, and also of the advances of the ice techniques in the world. A scientific skeleton has in principle been founded in the country both in sea ice research and sea ice related offshore activities, and this creates the possibility of a further development. New progress could be expected in the coming years in keeping pace with the modern achievements of sea ice engineering in the world.

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LITERATURE CITED

Coburn, J.L., *et al.*, 1984. *Bohai Sea Ice Design Criteria.* Report of Arctec Alaska.

Chen, X., 1986. Analysis of Ice Forces on Offshore Structures in Creep Mode of the Ice. Master degree thesis, Tianjin University.

Janbu, N., *et al.*, 1982. The Collapse of a Flare Jacket Subjected to Ice Loads. *Boss–82.*

Ji, X. H., *et al.*, 1988. A Study of Reference Stress Method for Bohai Sea Ice. *OMAE–88.*

Liu, T.F., *et al.*, 1987. Probabilistic Analysis of Sea Ice in the North Bohai Bay. *OMAE–87.*

Li, F.C., *et al.*, 1985. Probability analysis of design ice thickness in the Bohai Gulf. *POAC–85*, 1, 241-248.

Li, F.C., *et al.*, 1987. Study of the Flexural Strength and Elastic Modulus of Sea Ice in the Bohai Sea. *POAC–87.*

Maattanen, M., 1978. On Conditions for the Rise of Self-excited Ice-induced Autonomous Oscillations in Slender Marine Pile Structures. *Finnish Board of Navigation.*

Shen, W., *et al.*, 1986. Fracture Toughness of Bohai Bay Sea Ice. *OMAE–86.*

Shen, W., *et al.*, 1987. The Experimental Investigations on Scale Effect of Bohai Sea Ice. *OMAE–87.*

Song, A., *et al.*, 1988. An Ice Model Tank and Its Data Acquisition System, *Symposium on Cold Region Development.* (Harbin, China) 4, 311-323.

Sodhi, D.S., *et al.*, 1986. Characteristic Frequency of Force Variations in Continuous Crushing of Sheet Ice against Rigid Cylindrical Structures. *Cold Regions Science and Technology*, 12, 1-12.

Timco, G.W., 1984. Ice Forces on Structures: Physical Modelling Techniques, *The Special Volume of Proceedings I.A.H.R. on Ice.*

Timco, G.W., 1979. The mechanical properties of doped ice: A search for a better structurally simulated ice for model test basins. *POAC–79*, 1,719-739.

Vaudrey, K.D., 1977. Ice Engineering Study of Related Properties of Floating Sea Ice Sheets and Summary of Elastic and Viscoelastic Analysis. *Report R860*, Civil Engineering Laboratory, California.

Wang, R.S., *et al.*, 1985. Numerical experiments of sea ice in the Bohai Sea, *Acad Oceanologica Sinica*, 4(3).

Xu, J.Z., *et al.*, 1981 Dynamic Response of a jacket platform subjected to ice floe loads. *POAC–81*, 1, 502-516.

Xu, J.Z., *et al.*, 1985. Conditions and design criteria of sea ice in the Bohai Gulf. *POAC–85*, 1, 349-357.

Xu, J.Z., *et al.*, 1983. Features of frequency and amplitude in ice-induced vibration of a jacket platform. *POAC–83.*

Xu, J.Z., *et al.*, 1987. *Report on Feasibility Study of the Deeply Embedded Platform in the Liao-dong Bay.* Tianjin: Tianjin University.

Xu, J.Z., *et al.*, 1988. The ice force oscillator model and its numerical solution. *OMAE–88.*

Zhang, M.Y., *et al.*, 1983. A preliminary research for mechanical properties of sea ice in Bohai. *POAC–83*, 1, 79–88.

□ RÉSUMÉ □

Depuis la fin des années 60, les ingénieurs chinois sont confrontés dans le golfe de Bohai à des problèmes de glaces et de pétrole. Cet article présente le développement actuel et le statut de la recherche scientifique ou les pratiques de l'ingénierie civile liés aux glaces de mer dans cette région. Les tendances pour les années avenir sont prédites.—*Catherine Bousquet-Bressolier, Géomorphologie EPHE, Montrouge, France.*

□ ZUSAMMENFASSUNG □

In den späten 60er Jahren stießen chinesische Ingenieure im Golf von Bohai neben Ölvorkommen auf Probleme mit dem Meereis. Dieser Artikel beschreibt die seitdem erfolgte Entwicklung und den gegenwärtigen Stand der Forschung und des Ingenieurwesens in bezug auf Meereis in dieser Region. Zukünftige Entwicklungstendenzen werden zkizziert.—*Helmut Brückner, Geographisches Institut, Universität Düsseldorf, F.R.G.*

□ RESUMEN □

Los ingenieros chinos comenzaron a enfrentarse a los problemas debidos al hielo marino al descubrir petróleo en el Golfo de Bohai a mediados de la década de los sesenta. Este artículo introduce el desarrollo desde entonces hasta ahora de la investigación científica y de la práctica ingenieril relacionada con el hielo marino en la región. Se predice las tendencias en los años venideros.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*